AERODYNAMIC TESTING OF WING SECTIONS USING THE LASER DOPPLER VELOCIMETER

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ARO, Inc.

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ARNOLD ENGINEERING DEVELOPMENT CENTER
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NOTICES

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FOREWORD

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ABSTRACT

An experimental program was conducted in the low speed, two-dimensional wind tunnel to ascertain velocity distributions about a wing section. Velocity distributions were measured at various angles of attack using a laser Doppler velocimeter (LDV) and conventional pressure measuring techniques. In addition, an analytical method was developed to determine the pressure distribution over an arbitrary airfoil surface (including real fluid effects) given the geometry and coefficient of lift. The results of the different measurement techniques are compared with the analytical computations. Excellent agreement between both experimental techniques and real fluid flow theory was obtained.

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I. ILLUSTRATIONS

SECTION I
INTRODUCTION

The laser Doppler velocimeter (LDV) has been developed at AEDC as a useful and accurate velocity measuring instrument. Its applications to date, for aerodynamic testing, have been rather limited. However, many applications exist where the LDV can be a very beneficial tool—one being the testing of multielement high lifting wings.

The LDV offers several advantages over the conventional velocity measurement techniques. It does not disturb the flow since no material probes are introduced into the flow field. Point velocity measurements can be made in small areas where conventional instruments are either highly inaccurate or too bulky for installation. Fluctuating velocities can be measured directly, even at high frequencies, without time-averaging the data as encountered with conventional techniques. Also, the velocity function is measured directly rather than calculated.

A computer program has also been developed for calculating the pressure distribution over airfoil surfaces when the wing geometry and coefficient of lift are known. The method is an improvement over classical thin airfoil theory providing greater accuracy for thicker profile shapes. Compensation for real fluid effects is attained by using a reduced value of circulation. Results of the analytical computation are very good and appear to be limited only by the depth of the geometry input.

This report presents the results of an experimental program in which velocity distributions were measured about a wing section at various angles of attack with both the laser Doppler velocimeter and the conventional measuring technique and compared with the theoretical analysis.

SECTION II
APPARATUS

2.1 DESCRIPTION OF THE LOW SPEED WIND TUNNEL

The low speed wind tunnel is an open return facility capable of continuous flow. The tunnel has a bellmouth inlet with a 10.1 contraction ratio fitted with screen and honeycomb and is driven by a squirrel cage blower powered by a 7-hp variable speed motor.

The test section portion of the tunnel is removable so the tunnel can be operated with several test section configurations. For this study a two-dimensional 7- by 20-in. test section was used with 18-in.-diam Plexiglas® windows on both sides to permit optical probing of the two-dimensional flow about the airfoil. The velocity range for this test section is from 30 to 200 ft/sec. Figure 1, Appendix I, is a photograph of the experimental arrangement.

A digital readout was used to monitor wind tunnel fan speed. Pressures were measured by pressure transducers and Meriam micromanometers in conjunction with electrically driven scanner valves.

2.2 TEST ARTICLE

The test article consisted of a two-dimensional, symmetrical, wing section. The model had a 4-in. chord and 7.5-in. span and was supported at the tunnel sidewalls such that it could be rotated to any angle of attack. Static pressure taps were spaced chordwise at two spanwise locations 3-in. from each wall on both top and bottom surfaces. The model was a 12-percent-thick airfoil with a profile similar to a NACA - 0012 section (Ref. 1). Tables I and II (Appendix II) give the model dimensions and instrumentation locations, respectively. Figure 2 shows the model mounted in the wind tunnel test section.

SECTION III
LASER DOPPLER VELOCIMETER

The principle of operation of the dual scatter LDV is that particles in a flow field are illuminated by quasi-monochromatic radiation from a continuous-wave laser. The particles scatter the radiation at a frequency equal to the algebraic sum of the laser optical frequency and the Doppler shift frequency caused by the individual particle velocities. The scattered radiation is collected by a lens and focused into a photodetector which passes a signal to the electronic readout equipment.

The LDV used in this test was a dual scatter system (Ref. 2) used in the forward scattering mode, Fig. 3. In this system the velocity components are detected by heterodyning the radiations emanating from a common scatter center but from different illuminating beams. This is accomplished by simultaneously illuminating from two directions and viewing the difference frequency of the two superimposed rays generated by a common scatter center and propagated in a common direction. When

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they intercept a photodetector, simultaneously, they generate a Doppler current. Both one-component and two orthogonal component systems were used. The one-component system was used for measuring velocity distributions near the surface and the two-component system was used for far-field measurements. All the measurements were made outside the boundary layer.

SECTION IV
INSTRUMENTATION

A two-component LDV is shown in Fig. 4. Figure 5 shows the focal volume, where three beams intersect to measure two components of velocity. A 15-in. focal length lens was used in the test.

The LDV and its associated receiving optics were mounted on a three-degree-of-freedom traversing system so that any point in the wind tunnel test section could be measured. The position of the focal volume inside the test section was read out on a calibrated digital voltmeter. Figure 6 shows the laser and optics package of the LDV mounted on the traverse. The receiving optics and photomultipler (PM) tube are shown in Fig. 7.

A Spectra-Physics® Model 124 laser with 15-mw power output was used. The PM tube output was fed into a Hewlett-Packard ® 461A wide-band amplifier and then to the Doppler data processor signal conditioning electronics. The frequency of the signal was displayed on a Hewlett-Packard 5245 frequency counter. The output of the frequency counter was processed by a Hewlett-Packard 2515A digital scanner and then by a Hewlett-Packard 5050A digital printer for permanent record. A more detailed description of this system can be found in Ref. 3.

The wing section was fitted with 12 static pressure taps distributed chordwise on top and bottom surfaces. The pressure taps were connected to two 12- position scanner valves which fed a Meriam® Model 34FB2 micromanometer. Wind tunnel test section total and static pressures were monitored by means of a pitot static probe.

SECTION V
ANALYTICAL METHOD

Pressure distributions and net pressure coefficients were analytically determined for the airfoil section and compared with the experimental data. The analytical technique was developed by Chaudhuri (Ref. 4). The method is an improvement over classical thin airfoil theory in that it compensates for viscous effects and allows for greater

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accuracy for thicker profile shapes. Pressure distributions can therefore be calculated given the airfoil geometry and experimental lift coefficient.

The airfoil geometry is first approximated by taking into account the leading-edge radius, maximum thickness ratio, position of maximum thickness, and the trailing-edge slopes and ordinate. The actual ordinates of the airfoil are used to improve the matching at selected stations by means of a simplified form of Hermite, interpolation, polynomials. Viscous effects are accounted for by using a reduced value of the Kutta-Joukowski circulation. The reduced circulation is of the form $(1 - K)\Gamma$ where K is a function of the lift coefficient. This technique is valid for both symmetrical and cambered airfoil shapes. The accuracy of the method is a direct function of the detail of the geometry input.

SECTION VI
EXPERIMENTAL PROCEDURE

The velocity component measured by the LDV is that perpendicular to and in the plane of the two measuring beams. Before each test sequence the LDV beams were aligned across the test section such that the bisector of the angle between the beams was parallel to both the leading and trailing edges in addition to the upper and lower surfaces of the wing section. This ensured measurement of the velocity parallel to the leading edge of the wing section. The traverse position readout system was calibrated so that the position of the beam intersection was known anywhere in the test section. Natural contamination with absolutely no artificial seeding of the wind tunnel airflow was sufficient for all data acquisition.

The LDV beams were aligned such that they formed an isosceles right triangle (Fig. 5). The nature of the flow about the wing section is such that the horizontal velocity component is generally much larger than the vertical component. The Doppler data processor signal conditioning electronics used in this test are limited to a finite frequency range corresponding to a range of velocities. To ensure accurate measurements of two components of velocity, the triangle formed by the three beams was rotated to measure the components at ±45 deg to the axial tunnel centerline. Therefore the larger horizontal velocity was present in both measured components, and since they are orthogonal, the resultant velocity is easily resolved.

When measuring velocities at points very close to the wing section surface a one-component LDV system was used. The pyramid formed

by the three beams of the two-component system made it difficult to make measurements close to the wing surface since one of the beams was blocked by the test model. When measuring a single component the two beams were aligned parallel to the surface. At each pressure tap location, the component of velocity parallel to the surface was measured. All measurements were made outside the boundary layer.

A sample of 80 particle velocities was taken at each data point location. The data samples were then evaluated using a digital computer program which determines the mean velocity and the standard velocity deviation about the mean of the samples. When velocities near the surface of the wing were measured, pressure readings were taken simultaneously.

Tunnel total and static pressures were monitored by means of a pitot static probe. Free-stream velocity was also measured by the LDV. In all cases, the free-stream velocity measured by conventional tunnel instrumentation agreed within at least ±0.25 percent with the LDV data.

SECTION VII
RESULTS AND DISCUSSION

In Fig. 8, a comparison of the velocity measured by the laser Doppler velocimeter and that calculated from the pressure data using Bernoulli's equation, for an angle of attack of 0 deg, is presented. The velocimeter data were taken using a one-component dual scatter system aligned parallel to the wing surface. The discrepancy in the data near the leading edge is attributed to slight misalignment of the LDV beams with the true component of velocity. The high rate of change in flow direction in this area made it difficult to align the beams exactly parallel to the flow. This problem is not encountered with a two-component system since the true velocity direction can be directly resolved.

Referring to Fig. 8, note the inflection in the curve near the 60-percent chord station. This is attributed to an inflection on the airfoil surface resulting from fabrication.

Figures 9, 10, and 11 contain data of the net pressure coefficient at 2, 4, and 6-deg angle of attack, respectively. The net pressure coefficient is defined as

$$\Delta C_p = \frac{P_u - P_\ell}{q}$$

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where

$$p_u = \text{static pressure on upper surface}$$

$$p_\ell = \text{static pressure on lower surface}$$

$$q = \text{dynamic pressure}$$

In addition, the figures contain pressure data acquired by conventional instrumentation, velocimeter data, and analytical computations. Correlation between the pressure and velocimeter data are limited to the positions of the static pressure taps on the wing section. The analytical results break down near the trailing edge. This can be greatly improved with a more detailed mathematical description of the wing section geometry. The lift coefficient for a NACA-0012 airfoil (Ref. 1) was used for the analytical computations since the experimental lift coefficient for the test model was not known.

Velocity vectors of the flow field about the wing section, at an angle of attack of 12 deg, are shown in Fig. 12. The free-stream velocity was held at 100 ft/sec, and the velocity vectors are normalized (e.g., V/V_∞ where V_∞ is the free-stream velocity and V the velocity at the measuring point).

SECTION VIII
CONCLUSIONS

The results of the experiments show that the laser Doppler velocimeter is a reliable and accurate instrument for measuring velocities for most aerodynamic testing. Excellent results were obtained, with the LDV system, without introducing any artificial seeding in the flow. Eighty particle velocity samples were taken, at each data point, within a span less than 10 sec.

Measurements close to the surface were limited to one component by the LDV system used for this program. Two-component measurements can easily be made close to a surface by using a system having a longer focal length focusing lens, decreasing the angle between the three measuring beams. Backscattering techniques, where the scattered radiation is collected on the same side as the source, allow optical probing down to the surface itself. Boundary-layer measurements can be made by either of these systems.

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REFERENCES

1. Abbott, Ira H., von Doenhoff, Albert E, and Stivers, Louis S., Jr. "Summary of Airfoil Data." NACA Report 824, 1945.

2. Lennert, A. E. et al. "Summary Report of the Development of a Laser Velocimeter to be used in AEDC Wind Tunnels." AEDC-TR-70-101 (AD871321), July 1970.

3. Smith, F. H., Lennert, A.E., and Hornkohl, J. O. "Velocity Measurements in Aerodynamic Wind Tunnel (1T) Using a Laser Doppler Velocimeter." AEDC-TR-71-165.

4. Chaudhuri, S. N. "Contributions to some Problems on Wing Flow." PhD Dissertation, Bangalore, India, 1961.

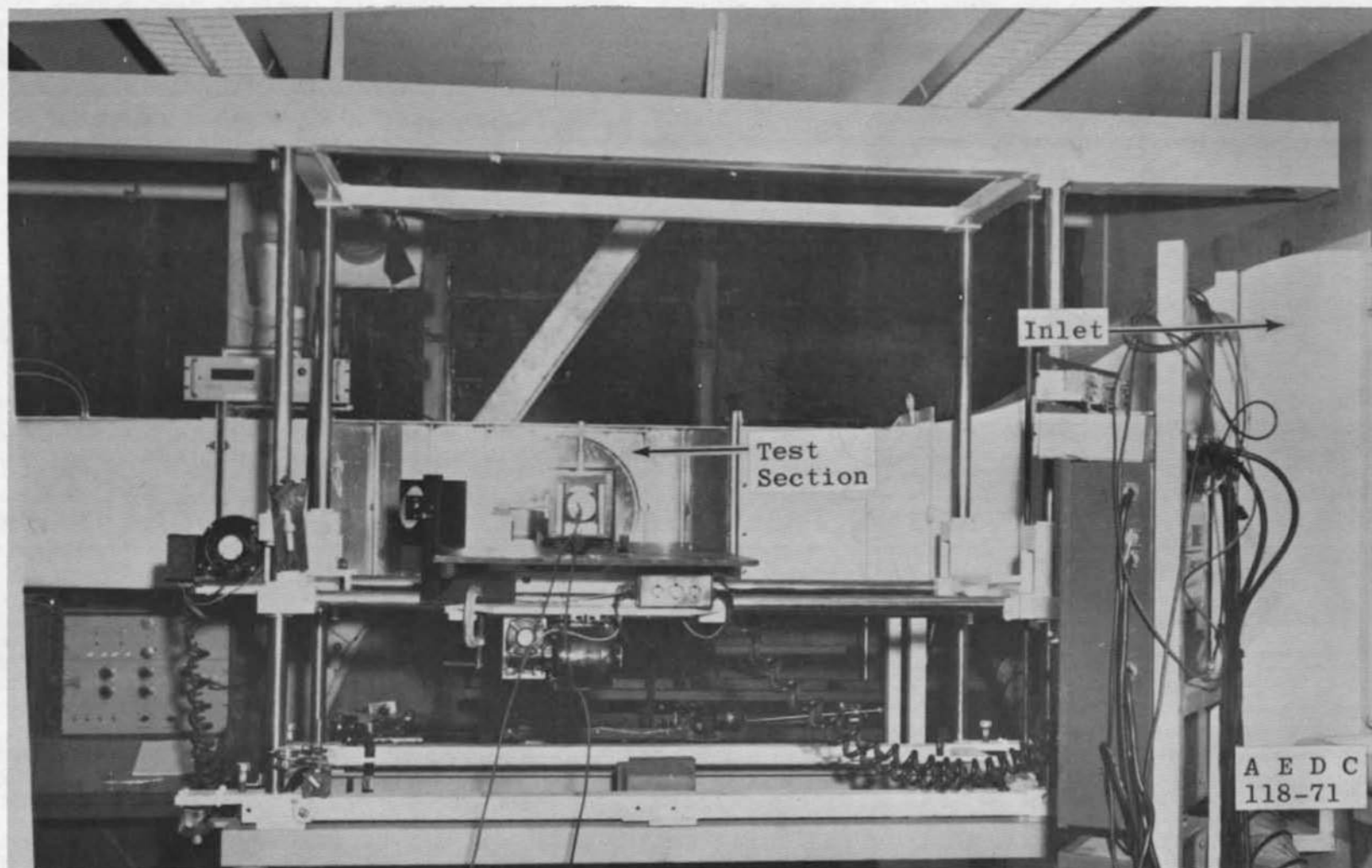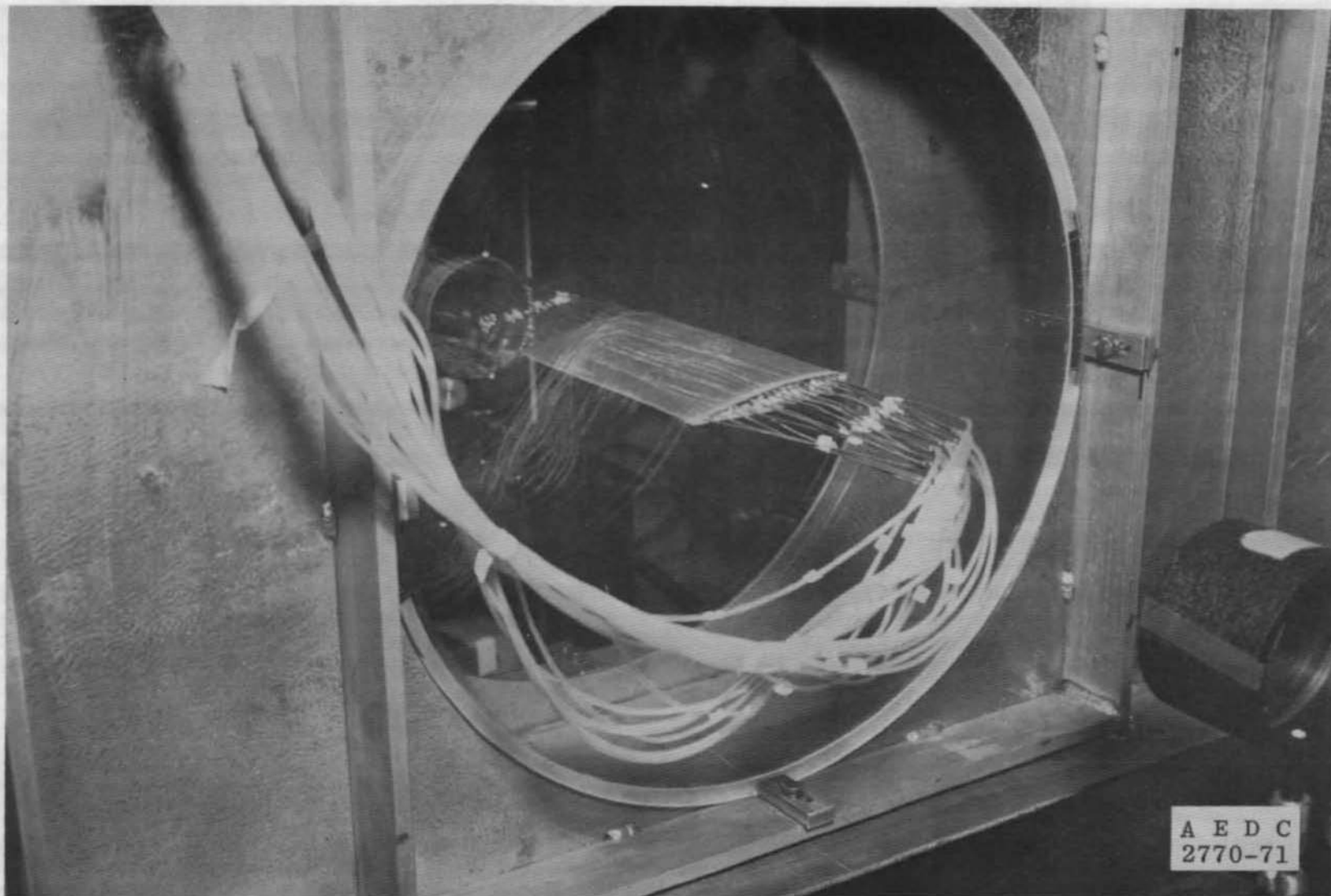**APPENDIXES**
I. ILLUSTRATIONS
II. TABLES

Inlet

Test
Section

A E D C
118-71

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Fig. 1 Low Speed Wind Tunnel

Fig. 2 Wing Mounted in Wind Tunnel Test Section

Collimated Gaussian Laser Beam

Optional Laser Beam Input

Y

f_L

(o,o,o)

D

θ

2b

B1

B2

2b

L1

Scattered
Rays

L2

PH

PM

Self-Aligning Illuminating Optics

B1, B2   Plane parallel blocks
L1   Focusing lens
L2   Collecting lens
(o,o,o)   Beam crossover region
PH   Pinhole
PM   Photomultiplier tube

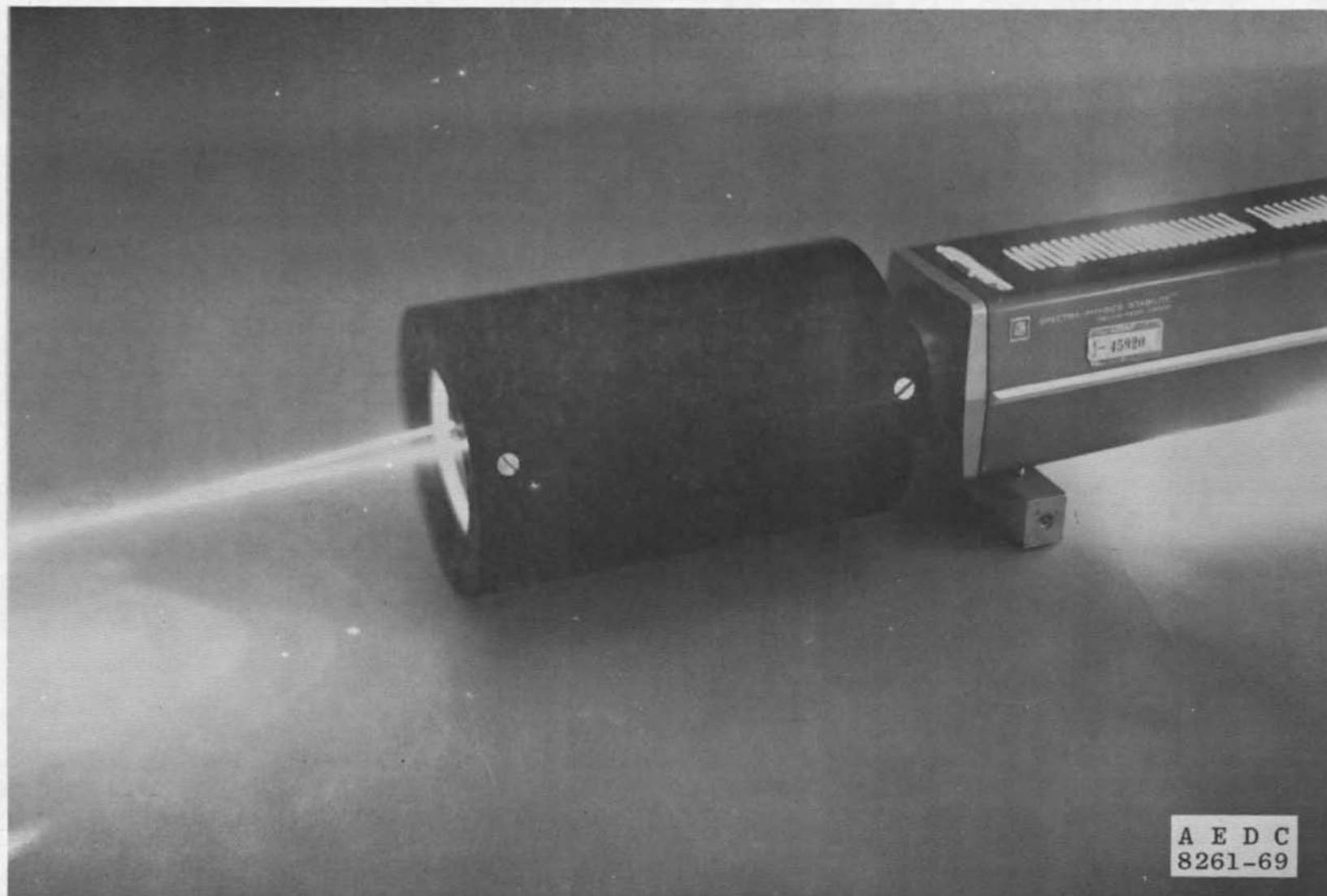Fig. 3 Schematic of Dual Scatter Laser Doppler Velocimeter

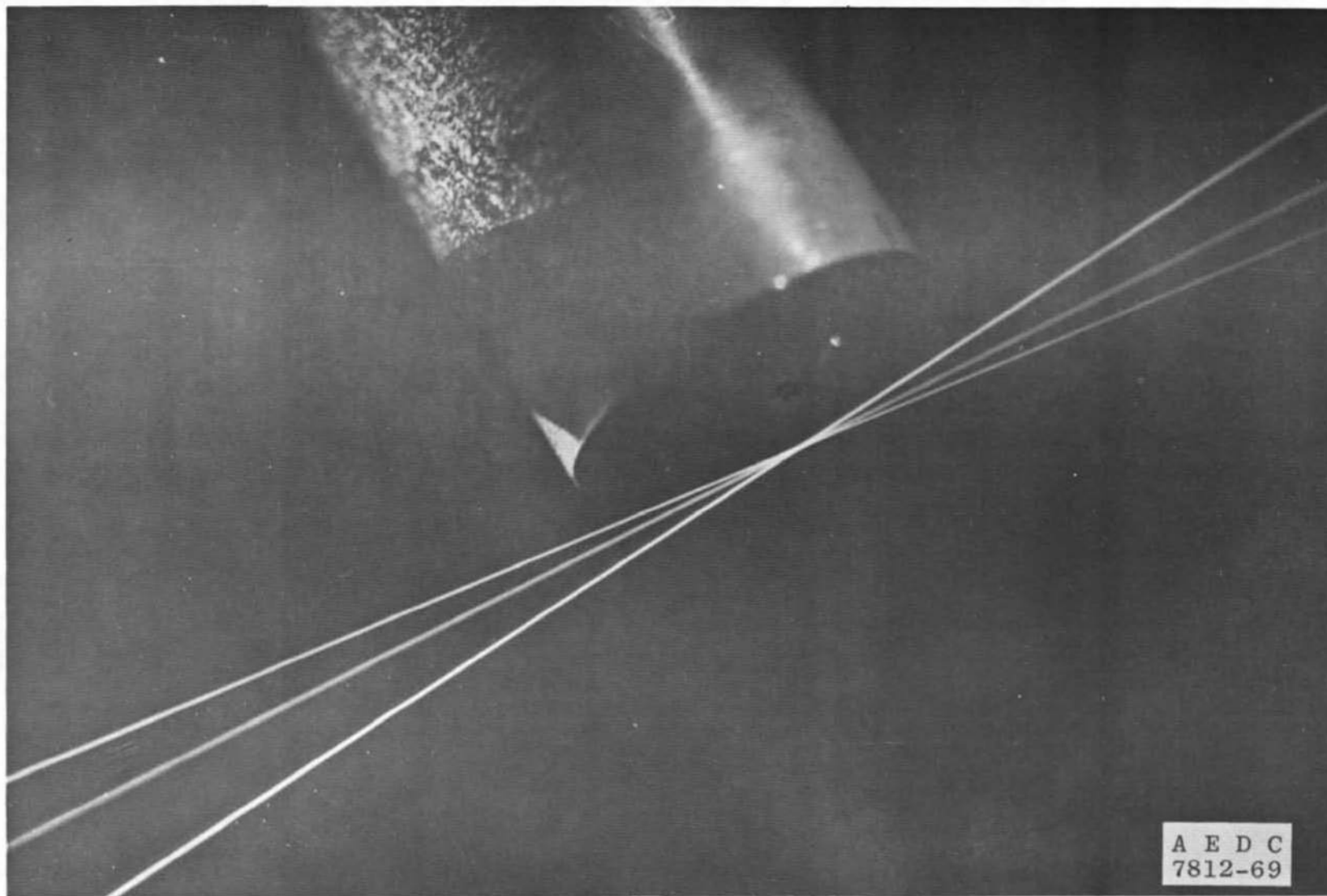Fig. 4 Two-Component Laser Doppler Velocimeter
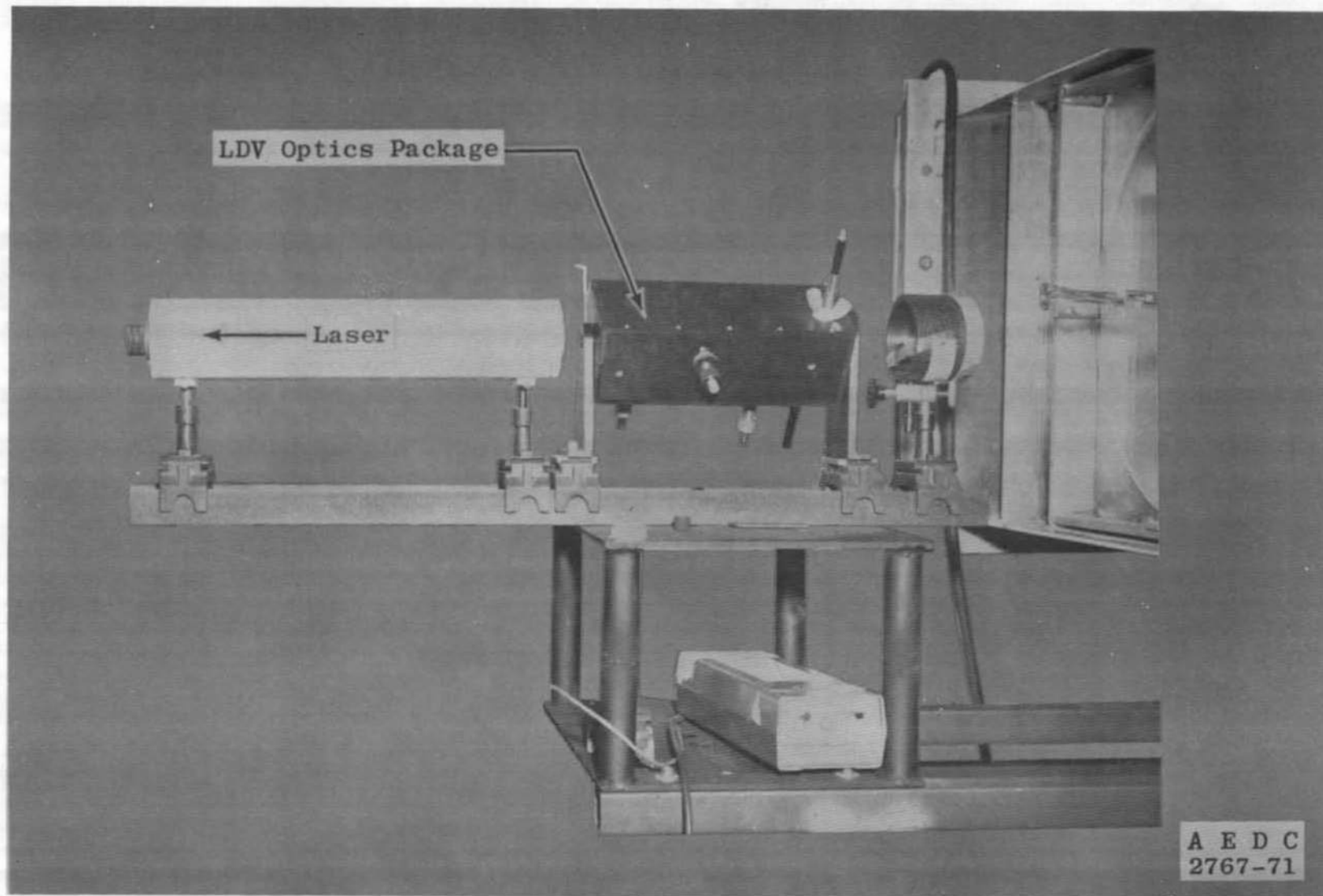
Fig. 5 Intersection of Beams

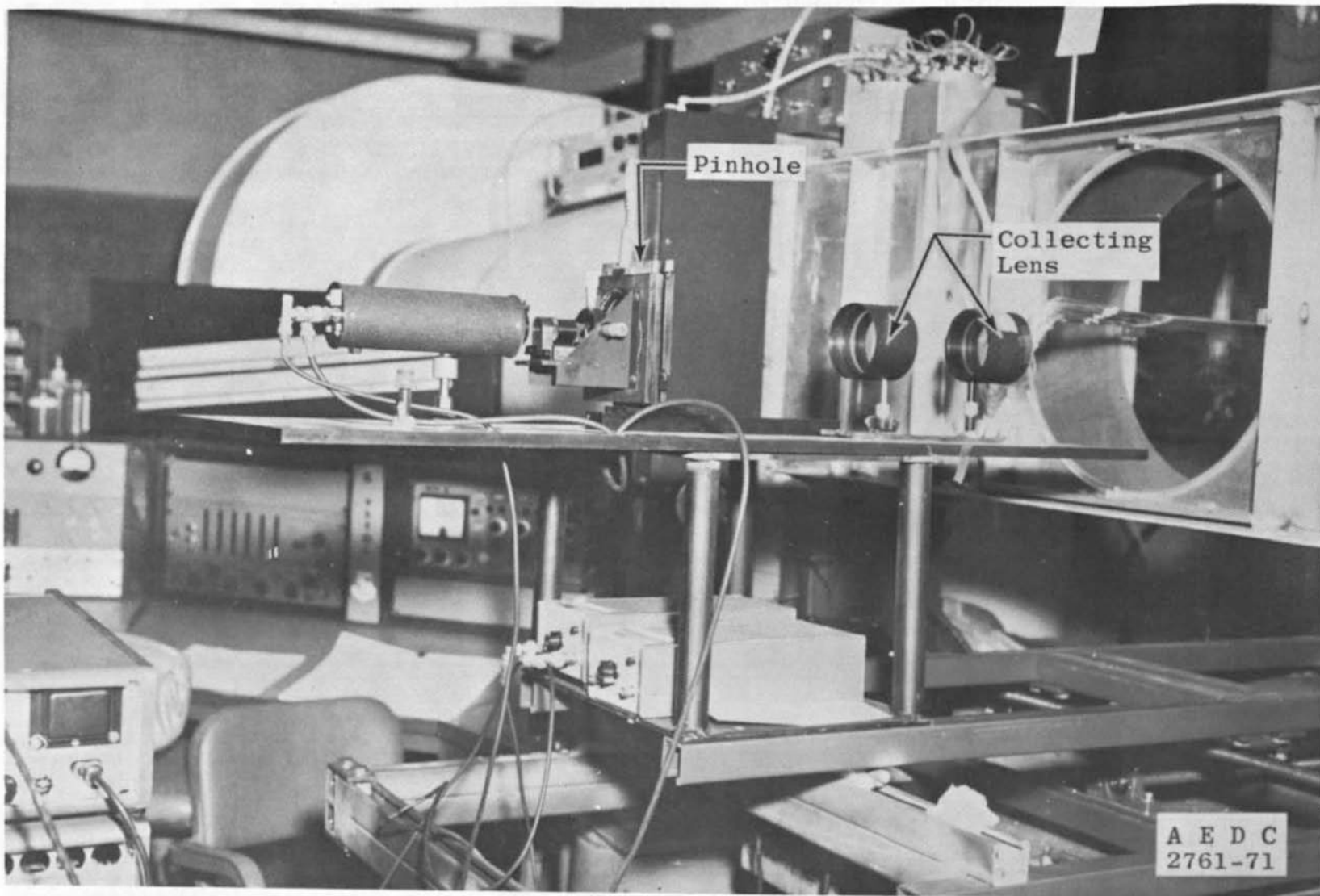Fig. 6 Laser and Optics Package on Traversing System

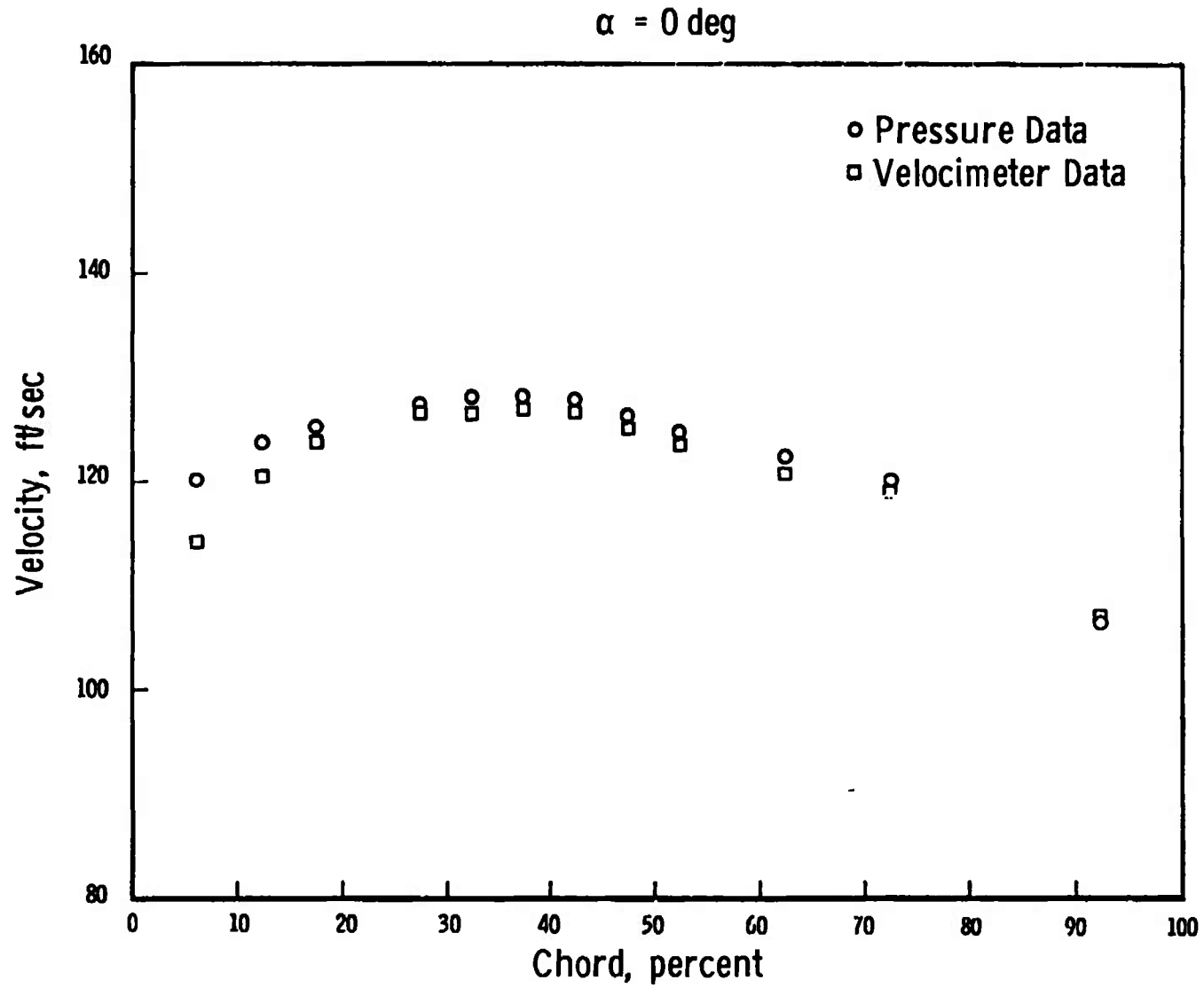Fig. 7 Receiving Optics and PM Tube on Traversing System

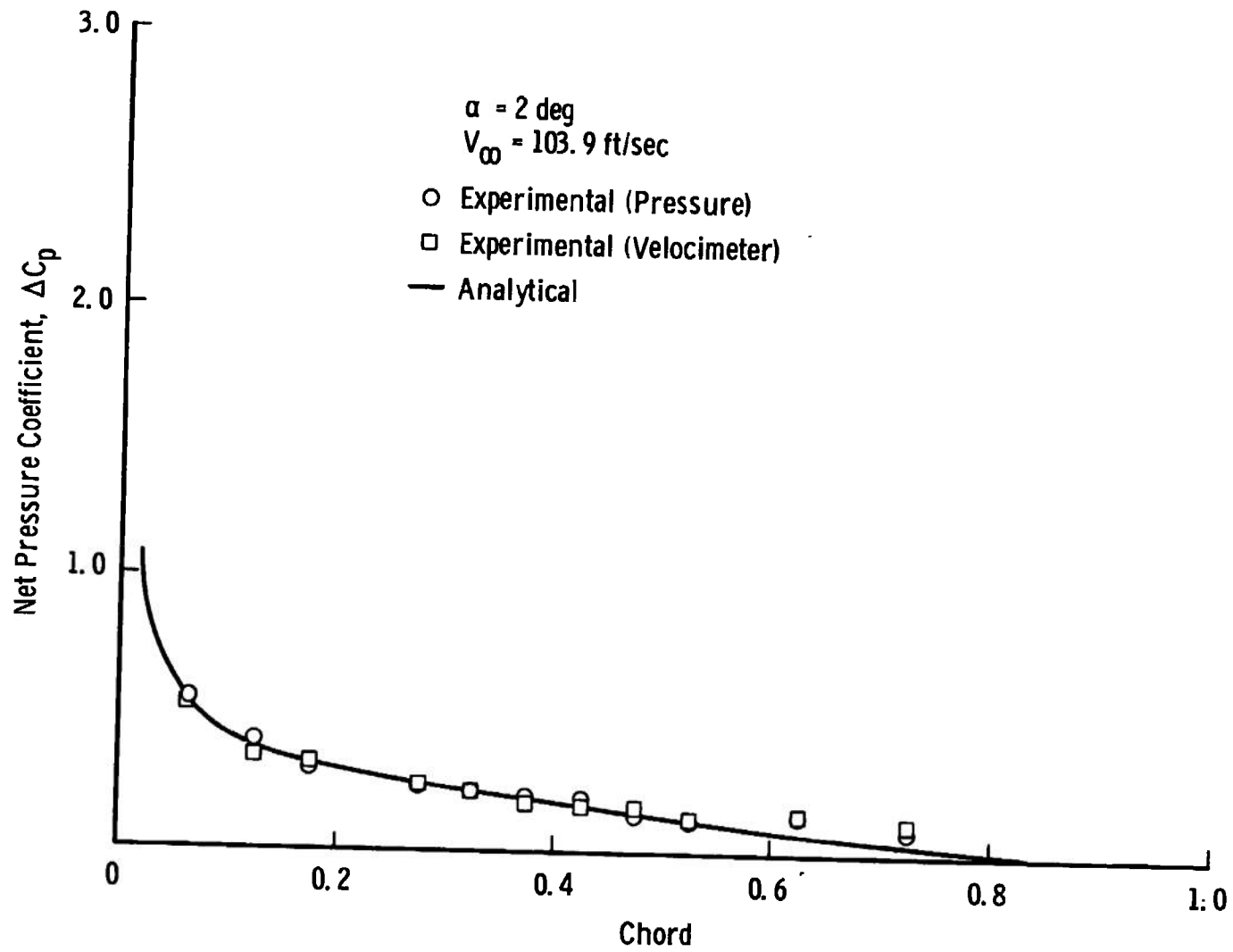Fig. 8 Velocity Distribution on Wing Surface at 0-deg Angle of Attack

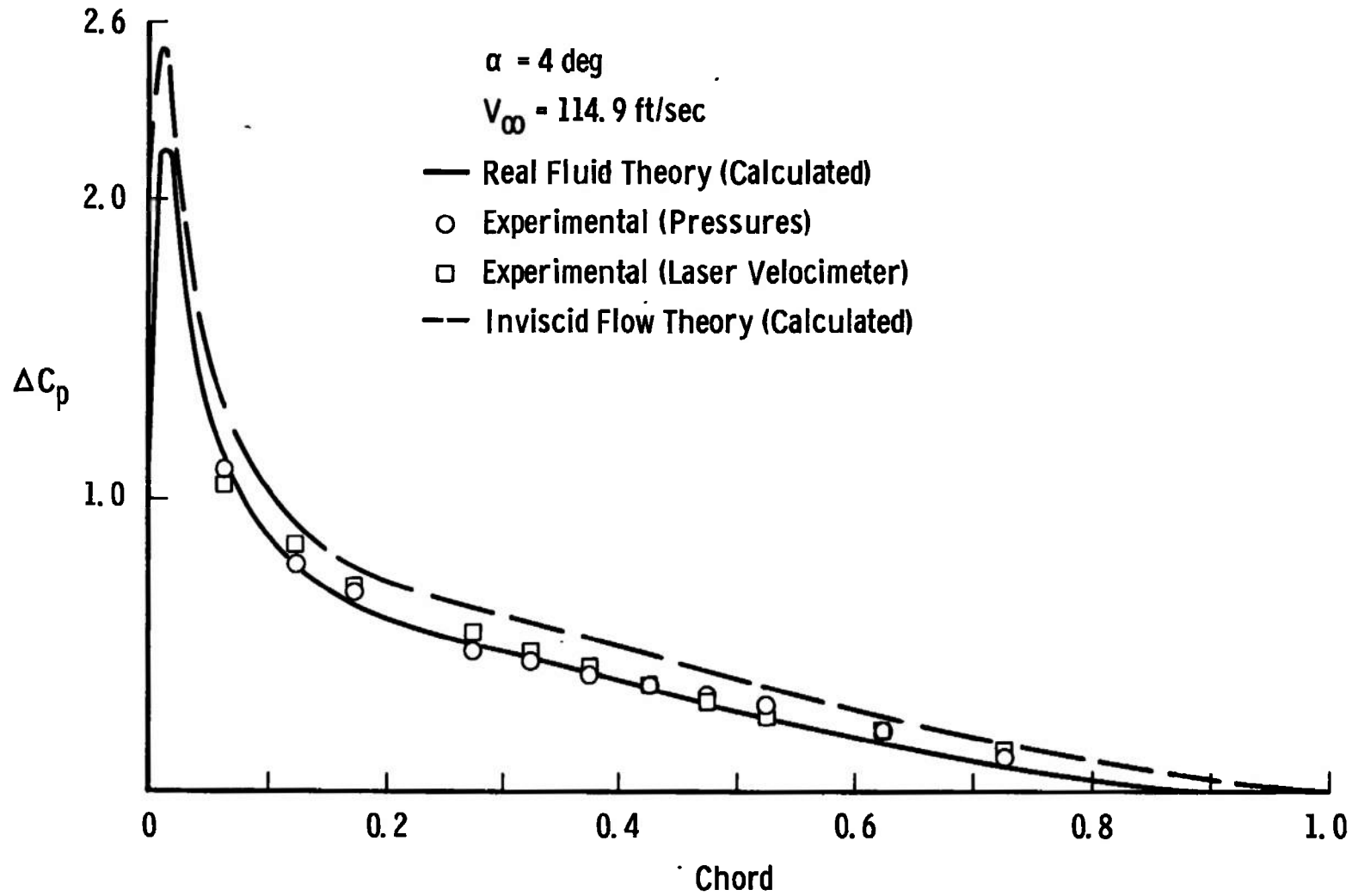Fig. 9 Net Pressure Coefficient at 2-deg Angle of Attack

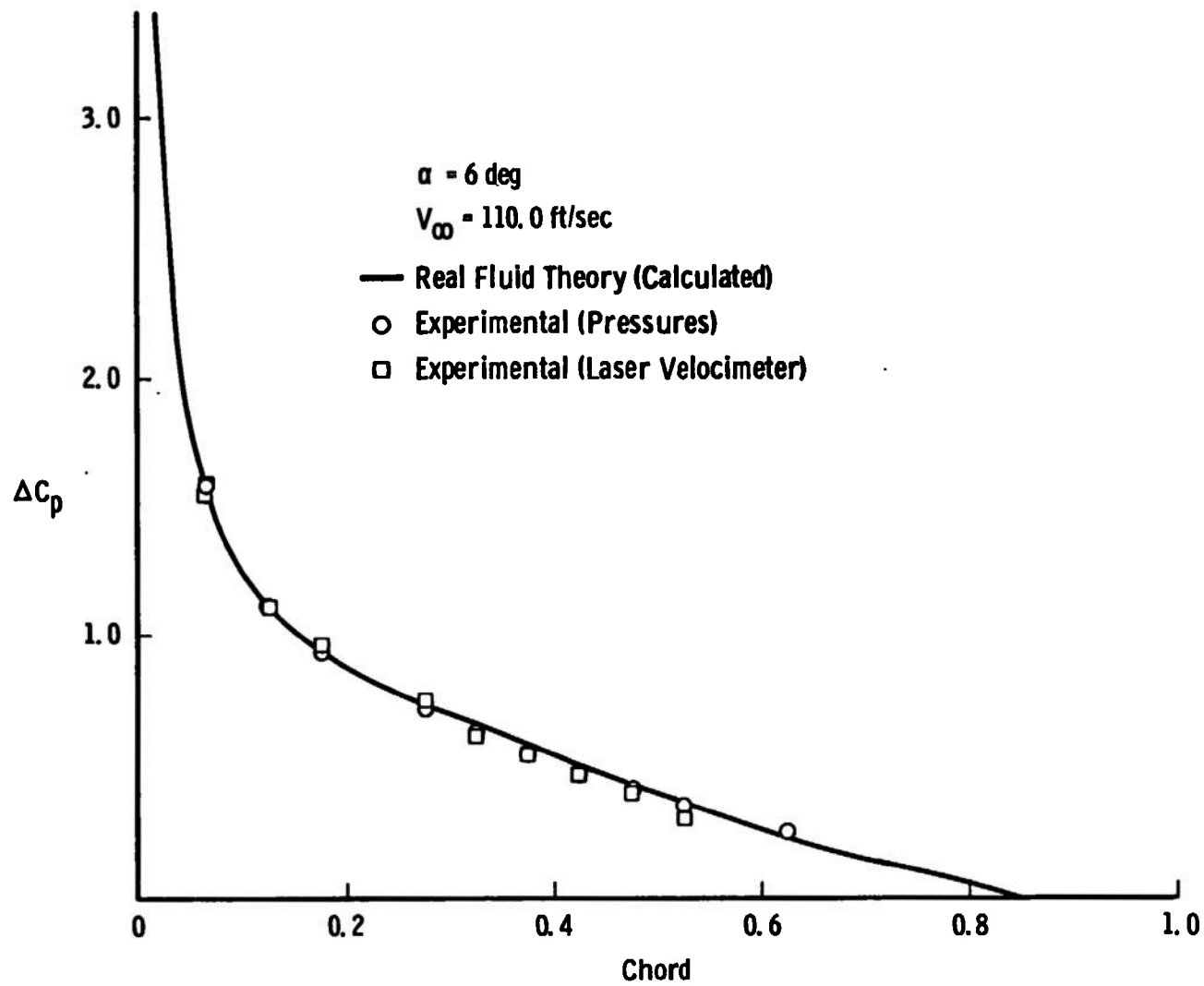Fig. 10 Net Pressure Coefficient at 4-deg Angle of Attack

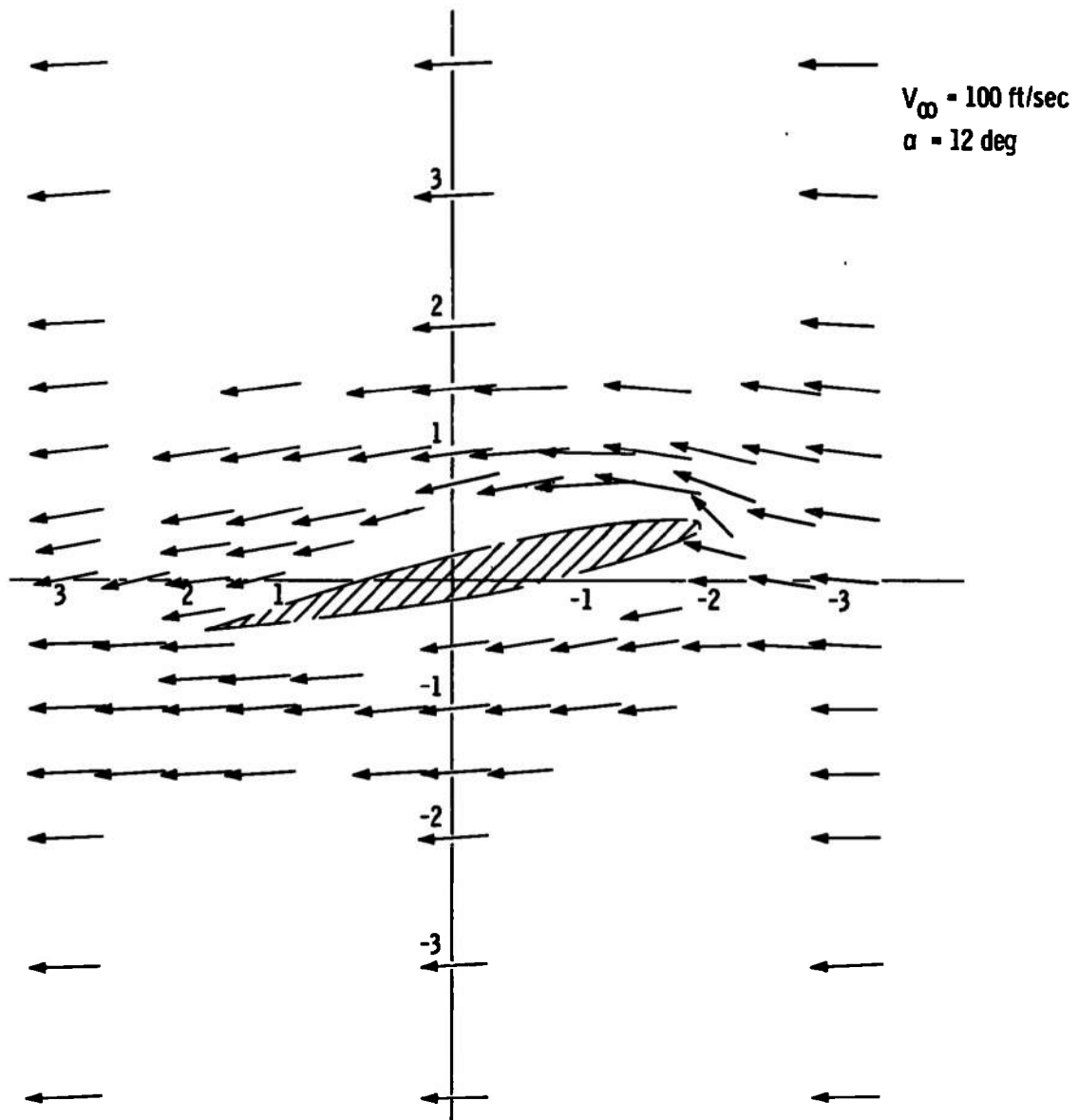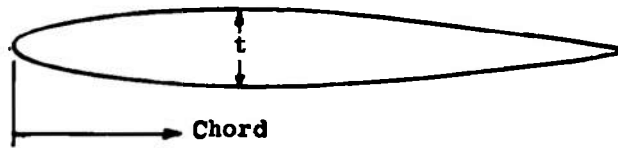Fig. 11 Net Pressure Coefficient at 6-deg Angle of Attack

Fig. 12 Flow Field about Wing at 12-deg Angle of Attack

TABLE I
WING GEOMETRY

2-D Wing Section

Station, percent Chord	t, in.	Station, percent Chord	t, in.
0.25	0.06628	36.71	0.48174
0.51	0.08749	39.24	0.48221
0.76	0.10269	41.77	.0.47991
1.01	0.11547	44.30	0.47511
1.27	0.12613	46.84	0.46704
1.52	0.13596	49.37	0.45677
1.77	0.14485	51.90	0.44410
2.03	0.15326	54.43	0.42930
2.28	0.16113	56.96	0.41271
2.53	0.16853	59.46	0.39445
2.79	0.17559	62.03	0.37476
3.04	0.18238	64.56	0.35292
3.29	0.18885	67.09	0.33208
3.54	0.19510	69.62	0.30920
3.80	0.20097	72.15	0.28572
6.33	0.24688	74.68	0.26076
8.86	0.29301	77.22	0.23739
11.39	0.32770	79.75	0.21273
13.92	0.35739	82.28	0.18818
16.46	0.38288	84.81	0.16349
18.99	0.40494	87.34	0.13885
21.52	0.42407	89.87	0.11398
24.05	0.44027	92.41	0.08913
26.58	0.45375	94.94	0.06443
29.11	0.46460	97.47	0.03964
31.65	0.47284	100.00	0.01467
34.18	0.47855		

Chord = 3.95 in.

Span = 7.50 in.

Leading-Edge Radius = 1.58-percent Chord

TABLE II
LOCATION OF INSTRUMENTATION ON WING

LOCATION	DISTANCE FROM LEADING EDGE, IN.
TOP	**TOP**
L	0.249
K and 11	0.507
J and 10	0.704
I and 9	1.104
H and 8	1.305
G and 7	1.504
F and 6	1.704
E and 5	1.901
D and 4	2.101
C and 3	2.501
B and 2	2.898
A and 1	3.698
BOTTOM	**BOTTOM**
M and 12	0.250
N and 13	0.506
O and 14	0.702
P and 15	1.104
Q and 16	1.302
R and 17	1.503
S and 18	1.703
T and 19	1.904
U and 20	2.103
V and 21	2.501
W and 22	2.901
X and 23	3.298

TABLE II (Concluded)

Leading Edge

TOP VIEW

L	L ●		● 11	11
K	K ●		● 11	11
J	J ●		● 10	10
I	I ●		● 9	9
H	H ●		● 8	8
G	G ●		● 7	7
F	F ●		● 6	6
E	E ●		● 5	5
D	D ●		● 4	4
C	C ●		● 3	3
B	B ●		● 2	2
A	A ●		● 1	1

Leading Edge

BOTTOM VIEW

M	M ●		● 12	12
N	N ●		● 13	13
O	O ●		● 14	14
P	P ●		● 15	15
Q	Q ●		● 16	16
R	R ●		● 17	17
S	S ●		● 18	18
T	T ●		● 19	19
U	U ●		● 20	20
V	V ●		● 21	21
W	W ●		● 22	22
X	X ●		● 23	23

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13. ABSTRACT

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14. KEY WORDS	LINK A		LINK B		LINK C	
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fluid flow						
gases						
wind tunnels						

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